

Radiation Exposures During the Biosatellite II Flight

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Experiments in space are the only way to determine whether identical radiations produce the same effects in biologic organisms on Earth as in the weightless state. One approach to the problem has been to send up biologic materials in a satellite and to measure the radiation to which they have been exposed (Crawford et al., 1962a). Usually the doses were very low and no biologic effect that could be attributed to radiation was seen. It was clear that in order to do an adequate experiment it would be necessary to expose samples to a controlled amount of radiation in flight. The Biosatellite II flight program was developed to meet this need.

Seven of the experiments flown on Biosatellite II were designed to determine the combined effects of radiation and weightlessness on lethality and mutagenesis in a variety of living systems. To accomplish this, they were exposed to an onboard source of radiation during the flight. Several months after the flight was successfully completed, a series of ground tests was initiated. The tests were designed to determine whether the observed effects of interaction could have been due to vibration and acceleration associated with the flight rather than to weightlessness.

EXPERIMENT DESIGN AND METHODS

For the flight, the biologic material from each experiment was divided into four groups. Each group was exposed to one of the following environments:

(1) Aboard Biosatellite II: Group A, radiation

and weightlessness; and group B, no radiation and weightlessness

(2) In the Earth control capsule: Group C, radiation and 1 g; and group D, no radiation and 1 g

Provisions had to be made in the capsule for an essentially radiation-free area for the control experiments and for the nonradiation experiments such as the frog egg and pepper plant experiments. Figure 1 shows the capsule divided into three main sections. The first, or forward, section contains the radiation source and the packages to be irradiated. A tungsten backscatter shield separates this section from the center section, the spacecraft equip-

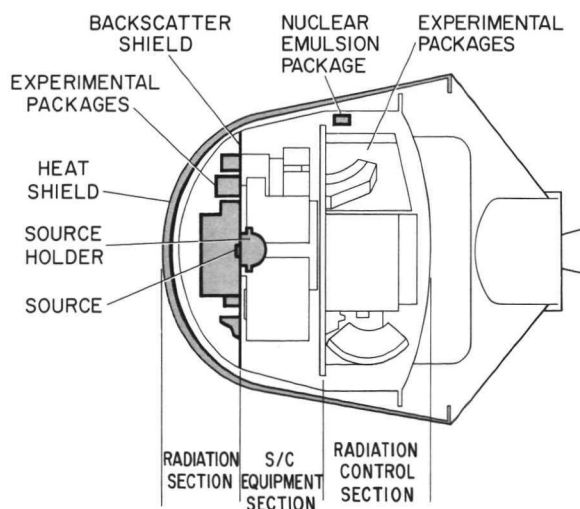


FIGURE 1.—Biosatellite 3-day capsule.

ment section. The third, or aft, section contains the control experiments. It was planned that the radiation exposures in this section should not exceed 1 roentgen (R) per day.

In selecting a radiation source, several factors were considered. It was desirable to irradiate all the packages at the same time, by use of a single source. The source had to be a gamma emitter. In the event that the capsule were lost, a short half-life would reduce the danger of exposure to someone who might accidentally find it. At the same time, the half-life had to be long enough so the source strength would not change appreciably during the planned 3 days of flight of Biosatellite II. The radioisotope finally chosen was 85-strontium, a gamma emitter giving off a single ray of 0.513-MeV energy. It has a half-life of 64 days.

Lithium fluoride (LiF) thermoluminescent powder was selected as the primary dosimeter. Each experiment package was monitored for radiation exposure by tubes of LiF powder attached to the outside of the package. Two pocket ion chambers were placed in the control area for an independent check of the low doses expected there. In addition, several of the experimenters had dosimeters within their packages. These are described in the individual experiment reports. The LiF powder was carefully readout postflight. A dose-response curve was established for the LiF with the use of an ^{85}Sr source. At least three readings were made on each sample and reference powders were read three times per day to detect machine drift.

The space radiation environment was monitored by a nuclear emulsion pack containing Kodak NTA, Ilford K.2, and Ilford G.5 emulsions (fig. 1). Because the emulsions, especially the G.5, are so sensitive to radiation, a tungsten well was made to shield the emulsion from the onboard source. The well was mounted next to the shell of the spacecraft in the control area. Its open side faced outward to accept protons and heavy ions entering the spacecraft.

Prior to flight, two paired radiation sources were received from the manufacturer. The sources, ARC No. 20 and ARC No. 21, were to be placed in the flight capsule and the Earth control capsule, respectively. The strength of each source was measured with a Victoreen R-meter which had been calibrated at the National Bureau of Standards and hand-carried to Cape Kennedy.

Source Capsule

Radioactive ^{85}Sr was produced by irradiating enriched $^{84}\text{Sr}(\text{NO}_3)_2$ with neutrons. The resulting powder was then poured into a stainless steel capsule, as shown in figure 2. The powder is retained within the capsule volume by welding the base plug in place. The finished capsule is shown in figure 3. Only the portion above the collar contains radioactive powder.

Radiation Source Holder

The purpose of the radiation source holder was to shield the radiation source before and after the exposure period and to shield the control experiment packages in the aft section of the Biosatellite capsule. It consisted of an approximately hemispheric mass of sintered tungsten. The holder is shown in figure 4. A wheel was mounted in the holder; a small section of the wheel projects above the top surface of the holder. In figure 5 the

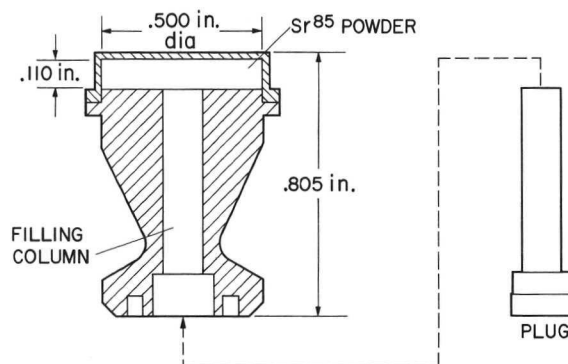


FIGURE 2.—Schematic of radiation source capsule and plug.



FIGURE 3.—Radiation source capsule.



FIGURE 4.—Radiation source holder.

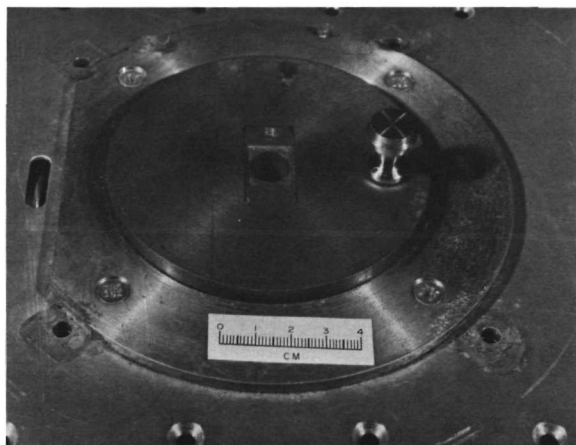


FIGURE 5.— Source capsule on top surface of source holder.

source capsule is shown resting on the top surface of the holder. The hole in the wheel into which the source capsule is inserted is also shown. When the wheel turns, the source is retracted and the intensity at the surface of the holder does not exceed 40 mR/hr.

Location of Experiment Packages

The optimum exposures for the test organisms ranged from 300 R for *Tradescantia* to 6000 R for one of the *Neurospora* samples. The packages were placed at different distances from the source so that each would receive its correct exposure in a nominal 65-hour exposure time. The distances were calculated from the inverse square law with the assumption of a point source of radiation. Figure 6 shows the arrangement of the packages.

Dosimeters

Three dosimetry packages are shown in figure 7. Dosimetry package No. 1 is shown to the right. It

was placed in the radiation area and contained film and LiF powder and was expected to receive a nominal 1000 R. The three items in the center of the figure are parts of dosimetry package No. 2. This package was placed in the control area. It contained two pocket ion chambers, one of 5-R capacity and another of 1-R capacity. Dosimetry package No. 3, shown on the left, contained the nuclear emulsion package in a tungsten well.

Postflight Testing

The postflight testing was conducted at NASA Ames Research Center. It was divided into three phases. The phase A test was primarily a dosimetry test designed to determine the amount of scattered radiation received by each package. Several experimenters felt it was necessary to make this determination because low-energy scattered radiation has a greater biologic effect than has high-energy radiation for the same exposure. A second objective of the test was to determine whether, in a series of runs, the difference between the radiation exposures measured in the flight and Earth control capsules would remain constant. There were no biologics in this test. The phase B test served to determine if the biologics would give the same response in each capsule with paired radiation sources and all other factors constant. The phase C test was designed to subject the flight capsule to acceleration and vibration the same as those measured during the flight while the Earth control capsule remained as a test control.

RESULTS

Flight Results

AMES RESEARCH CENTER MEASUREMENTS

The results of source strength measurements before flight are given in table 1. The sources are

TABLE 1. — Source Strength Measurements

Source	Source strength, mR/hr/meter	
	Measured	Average
ARC No. 20 (flight)	360	360
	360	
ARC No. 21 (Earth control)	360	
	354	357

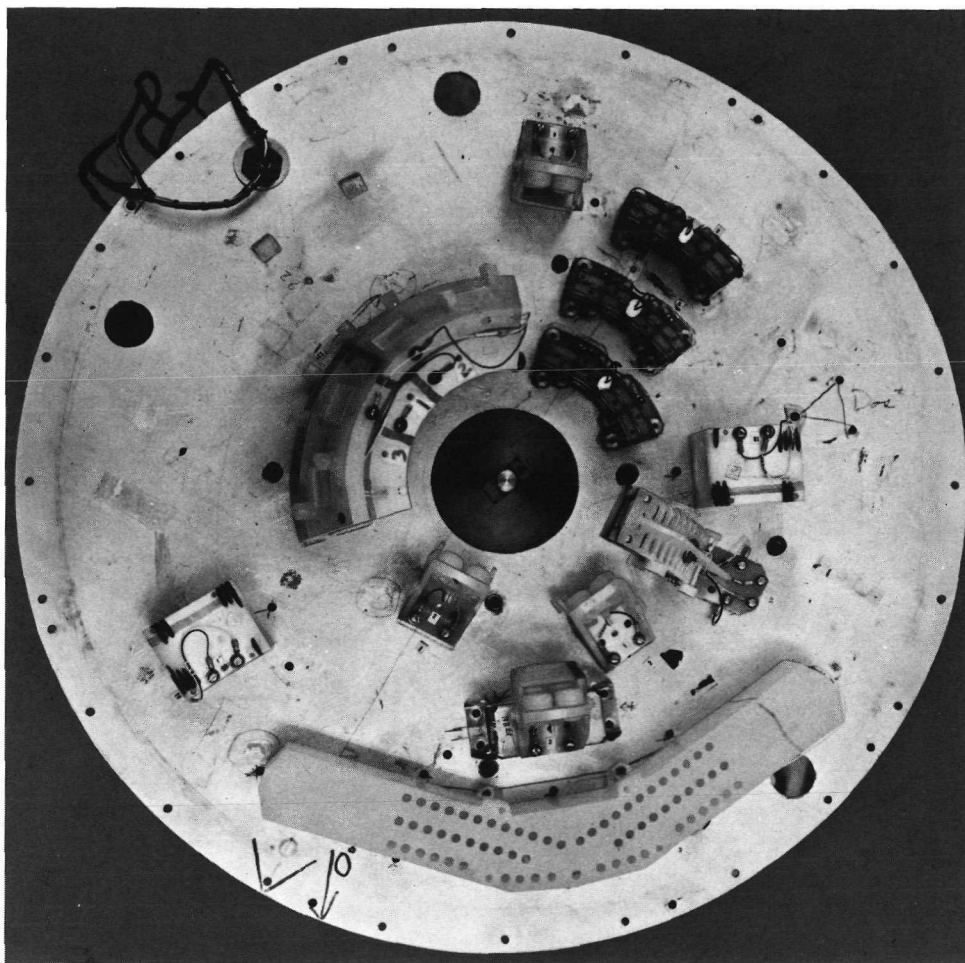


FIGURE 6.— Top view of packages arranged around radiation source. *Neurospora* bracket removed.

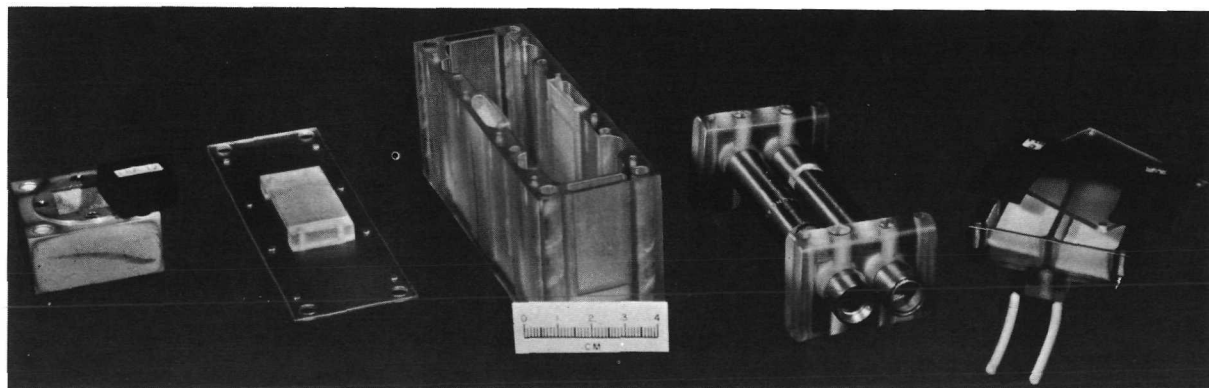


FIGURE 7.— Three dosimeter packages.

paired to within 1 percent. Table 2 gives the measured exposures to the LiF tubes attached to each experiment package. Except for the *Habrobracon* 1000 R package, most of the percent difference figures are within the accuracy of the reading method. The data indicate that for this flight the *Habrobracon* package bracket was reversed. Table 3 presents the radiation exposure of the biologic samples for four of the experiments. These values are calculated from the data in table 2. Table 4 shows that the dose in the control area was very small as measured by both LiF tubes and pocket ion chambers. The range is from 0.15 to 0.77 R.

NUCLEAR EMULSION MEASUREMENTS OF SPACE RADIATION¹

In the nuclear emulsion flight pack, densitometric doses due to gamma radiation were 43 mR at the top of the tungsten well and 21 mR at the bottom. Whereas the background caused by these doses did reduce the data available in the G.5 emulsion, it did not seriously interfere with the proton ender or heavy nuclei counts.

The flight pack in the tungsten well contained, from top to bottom, the following film sheets: Kodak Type 3 Double Component, 200-micron K.2, 100-micron G.5, 100-micron K.2, 200-micron K.2, NTA, NTA, 100-micron G.5, 200-micron K.2, and Kodak Type 3 Double Component. The 200-micron K.2 emulsion at the top was evaluated for proton enders and the 100-micron G.5 close to the bottom, for heavy nuclei. The enders count, based on a total of 806 identified enders, corresponds to a value of 8.24 enders per square millimeter of emulsion area. As systematic measurements on the last two Mercury and the Gemini missions have shown (Schaefer and Sullivan, 1967a), the enders count reflects, for the energy spectrum of trapped protons in the anomaly at satellite altitudes, the total dose in good first approximation for a given shield configuration. As the shield equivalent becomes lighter, the ratio of enders count to total dose becomes larger, yet the change is a rather weak function. Since the shielding for the radiation pack on Biosatellite II can safely be assumed to be lighter than that for the packs on the Gemini missions, application of the enders count calibra-

tion of the Gemini emulsions to the Biosatellite II data will overrate the actual dose. The dose measured is 48 mR and must be considered, for the just-explained reasons, an upper limit estimate for the actual proton exposure on Biosatellite II. It compares with a dose from trapped protons on the 14-day mission of Gemini VII of 230 mR. Expressed in dose rates, the two values correspond to 25.5 and 16.5 mR per 24 hours. Whereas a certain part of the difference is due to the indicated shielding influence on the conversion factor, a sizable part of the difference must be assumed to be real in view of the substantially smaller attenuation from the local hardware on the 940-pound Biosatellite II vehicle as compared with that on the 7-ton Gemini spacecraft. Just how much of the difference is to be attributed to either effect cannot be stated at this time. It is felt that the best estimate for the mission dose from trapped protons at the upper level of the tungsten well is 40 mR. For more heavily shielded locations inside the vehicle, the corresponding doses might have been substantially smaller.

Evaluation of the G.5 emulsion for heavy nuclei was carried out by the method used in Gemini VII (Schaefer and Sullivan, 1967b); i.e., the flux of very heavy nuclei of $Z \geq 20$ was determined by sorting out heavy tracks under the microscope according to the diameter of the solid silver core and the delta ray aura using a reference track of $Z=20$ in the atlas of Powell, Fowler, and Perkins (1959). The track made by a particle of this size during the flight is shown in figure 8. On the

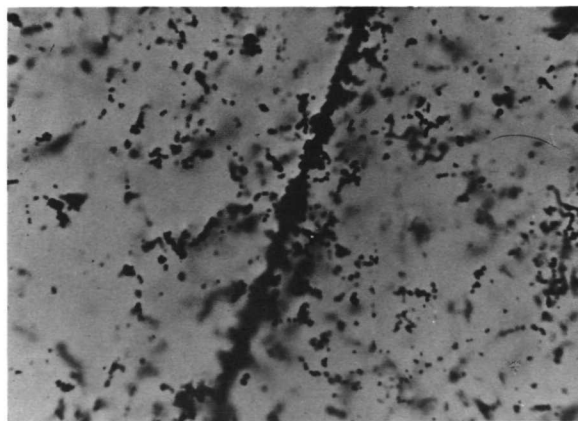


FIGURE 8.—Track of heavy cosmic ray in nuclear emulsion.

¹ The nuclear emulsion report was furnished by Dr. H. J. Schaefer, U.S. Naval Aerospace Medical Institute, Pensacola, Fla.

TABLE 2. — Radiation Doses to LiF Tubes

Package	LiF tube	Exposure, R		% difference, Flight — (Earth control) Flight
		Flight	Earth control 1	
<i>Habrobracon</i> , 4000 R.....	1	1440	1470	—2 to 3
	2	3570	3400	+5 to 6
<i>Habrobracon</i> , 2000 R.....	1	830	830	0
	2	1630	1600	+1 to 2
<i>Habrobracon</i> , 1000 R.....	1	420	503	—19 to 20
	2	650	825	—26 to 27
<i>Habrobracon</i> , 500 R.....	1	280	283	—1 to 2
	2	395	400	—1 to 2
<i>Tribolium</i>	1	1080	1070	+0 to 1
	2	1060	1030	+2 to 3
	3	775	770	+0 to 1
	4	750	745	+2 to 3
<i>Drosophila</i> larvae.....	1	660	655	+0 to 1
	2	655	655	0
	3	640	635	+0 to 1
	4	645	625	+3 to 4
<i>Drosophila</i> adult.....	1	1580	1505	+4 to 5
	2	1550	1560	—0 to 1
	3	1500	1460	+2 to 3
<i>Tradescantia</i>	1	310	307	+0 to 1
	2	316	312	+1 to 2
	3	205	207	—0 to 1
	4	207	205	+0 to 1
	5	295	288	+2 to 3
	6	300	295	+1 to 2
Lysogenic bacteria 2500 R.....	1	2250	2230	+0 to 1
	2	2250	2280	—0 to 1
	3	1270	1250	+0 to 1
	4	1260	1220	+3 to 4
Lysogenic bacteria, 1000 R.....	5	750	695	+7 to 8
	6	730	735	—0 to 1
	7	457	460	—0 to 1
	8	473	480	—1 to 2
Lysogenic bacteria, 500 R.....	9	254	253	+0 to 1
	10	300	302	—0 to 1
	11	213	206	+3 to 4
	12	215	220	—2 to 3
<i>Neurospora</i> , 6000 R.....	1	3600	3550	+1 to 2
	2	1160	1180	—1 to 2
	3	3525	3720	—5 to 6
	4	1160	1130	+1 to 2
<i>Neurospora</i> , 2500 R.....	1	1670	1710	—2 to 3
	2	685	675	+1 to 2
	3	1670	1630	+2 to 3
	4	720	740	—2 to 3
<i>Neurospora</i> , 1000 R.....	1	645	630	+2 to 3
	2	350	350	0
	3	625	640	—2 to 3
	4	350	350	0
<i>Neurospora</i> , 500 R.....	1	340	342	—0 to 1
	2	222	220	+0 to 1
	3	335	343	—2 to 3
	4	222	222	0

RADIATION EXPOSURES DURING THE BIOSATELLITE II FLIGHT

TABLE 3. — Radiation Doses to Biologics

Package	Exposure, R	
	Flight	Earth control 1
<i>Tribolium</i> , 1200 R.....	900	882
	877	861
	845	830
<i>Drosophila</i> larvae, 1300 R.....	832	822
<i>Drosophila</i> adult, 2000 R.....	1432	1404
Lysogenic bacteria:		
2500 R front chambers.....	1836	1840
2500 R back chambers.....	1456	1459
1000 R front chambers.....	697	674
1000 R back chambers.....	591	571
500 R front chambers.....	282	284
500 R back chambers.....	250	251

TABLE 4. — Radiation Measurements in Control Areas

Package	Radiation, R	
	Biosatellite II Flight	Biosatellite II Earth control 1
<i>Habrobracon</i>	0.38	0.43
	.43	.47
<i>Tribolium</i>	.42	.48
	.45	.49
	.33	.45
	.36	.47
<i>Drosophila</i> adult.....	.24	.32
	.27	.33
	.20	.28
<i>Tradescantia</i>	.23	.33
	.20	.35
	.25	.40
	.27	.40
<i>Drosophila</i> larvae.....	.36	.77
	.18	.64
	.32	.71
<i>Neurospora</i>	.60	.28
	.19	.23
	.19	.28
	.15	.19
Lysogenic bacteria.....		.51
	.43	.46
Ion chambers:		
1.0-R chamber.....	.22	.25
5.0-R chamber.....	.28	.34

basis of a total of 25 identified tracks of $Z \geq 20$, a flux of $Z \geq 20$ nuclei of $10.1/\text{cm}^2$ was found. Since this is the total mission flux, it corresponds to a flux of $5.4/\text{cm}^2$ day. This value matches very closely the theoretical value since it follows from the existing data on the heavy galactic flux. Assuming that the close agreement between the observed flux for $Z \geq 20$ nuclei and the theoretical value can be extended to the entire galactic flux, one obtains a mission dose of 2.9 mR from galactic radiation.

It must be expressly stated that a substantial fraction of these 2.9 mR are due to heavy nuclei and that the radiobiologic significance of this particular part of the exposure is not adequately expressed in terms of absorbed dose. Investigators with experiments aboard Biosatellite II who wanted to establish hit numbers from passage of individual heavy nuclei through the microstructure of their respective biologic specimens were referred to the

value of 10.1 traversals of nuclei of $Z \geq 20$ through a target area of 1 cm^2 during a time span of 45 hours in orbit. This flux can be assumed to be essentially constant throughout the entire interior of the vehicle assembly. The hit numbers for lighter nuclei have been calculated by using the flux ratios of the $Z \geq 20$ group to the lighter groups (Schaeffer and Sullivan, 1967b), as presented in table 5.

TABLE 5. — Calculated Fluxes of Galactic Heavy Nuclei

Elements	Z	Flux, nuclei/ $\text{cm}^2/42 \text{ hr.}$
Li, Be, B.....	3, 4, 5	30.3
C, N, O, F.....	6, 7, 8, 9	108.0
Ne→K.....	10→19	27.3
Ca→Ni.....	20→28	10.1 measured

TABLE 6. — Representative Scattering Measurements

Package	Run 1				Run 2			
	Set	CaF ₂	LiF	% <100 keV	Set	CaF ₂	LiF	% <100 keV
<i>Tradescantia</i>	1	63.1	62.4	0.7	130	52.3	46.0	1.8
	5	50.4	47.7	.8	134	45.2	40.1	1.7
	10	57.3	53.5	1.0	138	63.5	56.0	1.8
	15	57.4	52.7	1.2	140	48.2	44.1	1.3
	20	65.4	59.4	1.4	142	45.7	44.9	.2
<i>Drosophila</i> adult	21	378	346	1.2	150	380	371	.3
	25	357	344	.5	155	384	342	1.7
	30	422	361	2.3	160	399	358	1.6
	35	384	360	.9	165	390	365	.9
<i>Drosophila</i> larvae.....	37	243	233	.6	168	255	236	1.1
	40	254	233	1.2	170	242	234	.5
	45	238	235	.2	175	249	225	1.4
	50	233	223	.6	180	235	203	2.1
<i>Tribolium</i>	53	228	212	1.0	.....	.....	.....	.....
	55	252	229	1.4	.....	.....	.....	.....
	57	252	238	.8	.....	.....	.....	.....
Lysogenic bacteria, 2500 R.....	60	288	397	— .3	190	444	410	1.1
	65	515	440	2.3	195	397	324	3.1
	70	445	447	0	200	378	337	1.6
Lysogenic bacteria, 1000 R.....	75	181	175	.5	206	178	165	1.1
	80	160	160	0	210	181	183	.2
	85	183	137	4.5	215	164	140	2.3
Lysogenic bacteria, 500 R.....	91	79.1	73.0	1.1	220	75.9	60.0	3.6
	94	48.5	56.9	— 2.0	225	82.5	74.2	1.5
	100	82.8	75.3	1.3	229	79.6	72.3	1.4
<i>Habrobracon</i>	1	756	641	.3	14	159	147	1.1
	10	103	94.2	1.3	20	79.1	73.1	1.1

Postflight Test Results**PHASE A**

A measure of the amount of scattered radiation to which the packages were exposed is given in table 6. The primary radiation has an energy of 0.513 MeV. Its energy is reduced by each scattering event. In order to measure that percentage with energy degraded below 100 keV, paired sets of miniature CaF_2 and LiF dosimeters were placed inside the packages. Since the response of CaF_2 increases greatly below this energy and that of LiF does not, it was possible to calculate the percentage from the difference of the two dosimeter readings.²

In almost all cases the values are less than 2 percent.

Table 7 gives the differences in the dosimeter readings for corresponding locations in the flight (301) spacecraft and the Earth control (201) spacecraft during the three runs. Problems were encountered with unstable LiF during this test. A batch of LiF was received which lost, within a few days, as much as 25 percent of the energy it had absorbed when it was irradiated. This made it impracticable to convert the LiF readings to roent-

² These measurements were made by Edgerton, Germeshausen & Grier, Inc., Goleta, Calif.

TABLE 7. — Comparison of LiF Readouts in 301 and 201 Spacecraft, Phase A Tests

Package	LiF tube	Run 1, % difference (301 - 201)/301	Run 2, % difference (301 - 201)/301	Run 3, % difference (301 - 201)/301
<i>Habrobracon</i> :				
4000 R.....	2	-6.3	-3.3	+2.8
2000 R.....	2	+8	+5.4	+3.6
1000 R.....	2	-28.0	-27.0	+7.4
500 R.....	2	+3.4	-7.0	-1.1
<i>Tribolium</i>	1	+1.0	-2.5	-8.2
	2	+2.3	-2.3	-5.5
<i>Drosophila</i> larvae.....	1	-3.8	0	-1.0
	2	-7.0	-8.7	+4.3
	3	-2.1	+4.2	+2.4
	4	-1.2	+2.1	+8.9
<i>Drosophila</i> adult.....	1	-3.6	-3.6	+2.2
	2	0	0	+1.9
	3	+2.2	-6.4	+1.0
<i>Tradescantia</i>	3	-2.9	+2.9	-5.3
	4	+3.4	0	-4.3
Lysogenic bacteria:				
2500 R.....	1	+7.0	-11.8	-.7
	2	+.2	-6.7	-7.8
1000 R.....	1	0	-5.4	+1.9
	2	0	-5.9	-8.5
500 R.....	1	+2.8	-3.0	+7.0
	2	+1.4	+6.0	0
<i>Neurospora</i> :				
6000 R.....	1	-3.6	-5.5	+6.0
	3	+2.1	+3.5	0
2500 R.....	1	+3.6	+5.1	—
	3	-.4	+3.9	0
1000 R.....	1	+5.1	-2.2	+1.8
	3	+5.1	-2.2	+1.8
500 R.....	1	0	+4.2	-.4
	3	+3.7	-8.3	+1.2
Net percent difference.....		+.36	-2.12	+0.01

gen values. However, since the data in table 7 are derived from paired LiF readings, the percent difference values are acceptable. The net differences for each run are small; the large values recorded for the 1000 R *Habrobracon* package in runs 1 and 2 were caused by the bracket of this package being mounted backward as it was in the flight. After this test, the LiF powder was replaced by the manufacturer.

PHASES B AND C

The source strength measurements for the phase B and C tests are given in table 8. The initial calibrations of the phase B sources indicated a difference of 3 percent between source strengths. The manufacturer reported a difference of 1 percent. In order to resolve this discrepancy, another series of runs was made after the test. The results are

given in table 8. The values are higher in these runs since they were not made at 1 meter. The relative values of 649 and 653 indicate agreement to within 1 percent. It seems probable that the value of 346 in the original measurements was too low. The strengths of the phase C sources were closely paired; however, the measured intensities are about 4 percent lower than those of the sources used in Biosatellite II and the phase B test.

The *Tribolium*, *Habrobracon*, and adult *Drosophila* experiments required irradiation of some of the animals with X-ray prior to testing. A GE Maxitron was used for this purpose. The X-ray parameters are given in table 9. They were kept constant for both tests, except for variations of a few percent in dose rate.

The radiation exposures at the LiF tube positions and to the biologic are given in tables 10

TABLE 8. — Source Strength Measurements, Phase B and C Tests

Source	Source Strength, mR/hr/m	
	Measured	Average
Phase B		
ARC No. 27 (201 capsule)	364	
	346	354
	353	
ARC No. 28 (301 capsule)	367	366
	365	
Phase B, repeat (not at 1 m)		
ARC No. 27	649	
	652	649
	647	
ARC No. 28	655	
	654	653
	649	
Phase C		
ARC No. 29 (201 capsule)	345	342
	340	
ARC No. 30 (301 capsule)	341	345
	349	

and 11. For both tests, there is good agreement between the paired positions in the 301 and 201 spacecraft. The net percent differences are +0.35 and -0.15 percent for the phase B and phase C tests, respectively. The large value shown for the *Habrobracon* 1000 R package in the phase C test indicates that its bracket was reversed as it was during the actual flight. As expected, exposures in the control areas were low. The measured values are given in table 12.

DISCUSSION

For the first time, controlled radiobiologic experiments have been conducted in orbital flight. A wide range of biologic material has been flown to determine the effect of weightlessness and radiation on genetic and somatic end points. The use of paired radiation sources permitted the delivery of almost identical radiation exposures to the flight and Earth control packages. This was an essential requirement since it was expected that some of the effects due to weightlessness might be quite small.

The use of ^{85}Sr as a source proved to have disadvantages. The short half-life is troublesome in the face of the uncertainties of launching a satellite. Since the sources were decaying at the rate of 1 percent per day, it was necessary to have a new pair arrive each 5 or 6 days in case the launch was delayed. Consideration should be given to the use of an isotope with a longer half-life, if a similar flight is planned for the future.

The nuclear emulsion measurements verify again that the doses due to space radiations are very low

in orbits similar to that of Biosatellite II. It should be pointed out that the radiation exposures from the onboard source were much higher than those one would normally receive from space radiation. For example, the Discoverer XVII flight (Crawford et al., 1962b) took place during a large solar flare. The spacecraft was placed in a polar orbit. During a 50-hour period, an exposure of 30 R inside the vehicle was recorded. Most of the exposure took place as the spacecraft crossed the polar regions where the magnetic field of the Earth offers little shielding. Even if the spacecraft had been located far from the Earth, it is improbable that the exposures would have exceeded the highest doses delivered aboard Biosatellite II.

The postflight tests were extremely valuable to the experimenters in aiding them to distinguish effects which might be due to a vibration and acceleration (centrifuge simulation) rather than to weightlessness.

The results of the dosimetry measurements indicate that it is highly unlikely that any difference found between the biologic responses of the same experiment in the flight and Earth control capsules can be attributed to radiation exposure differences, nor can any unusual results be attributed to the presence in the capsules of a large component of low-energy radiation produced by multiple scattering.

SUMMARY AND CONCLUSIONS

The biologic specimens which were flown in Biosatellite II received the same radiation exposure

TABLE 9. — X-Ray Parameters, Phase B and C Tests

Experiment	kVp	mA	Aluminum filter, in.	Target distance, in.	Phase B		Phase C	
					Dose rate, R/min	Exposure, R	Dose rate, R/min	Exposure, R
<i>Tribolium</i>	180	5	0.042	11.5	102.3	1350	106	1310
<i>Habrobracon</i> ^a	180	10	.092	12.0	120.0	360	124.8	.....
						720	.....	720
						1200	.....	1200
						2000	.....	.....
						2400	.....	2400
								4000
<i>Drosophila</i> adult	190	15	.092	11.5	215	4000	211	4000

^a 2 mm of plastic were placed over the *Habrobracon* packages to attain electron equilibrium.

TABLE 10. — Radiation Doses to LiF Tubes, Phase B and C Tests

Package	LiF tube	Phase B			Phase C		
		Exposure, R		% difference, (301-201)/301	Exposure, R		% difference, (301-201)/301
		301 S/C	201 S/C		301 S/C	201 S/C	
<i>Habrobracon</i> , 4000 R.....	1	1400	1470	-5.0	1490	1480	+0.7
	2	3380	3480	-3.0	3370	3300	+2.1
<i>Habrobracon</i> , 2000 R.....	1	835	825	+1.2	782	785	-.4
	2	1580	1540	+2.5	1510	1550	-2.6
<i>Habrobracon</i> , 1000 R.....	1	491	508	-3.5	410	497	-21.2
	2	800	840	-5.0	625	810	-29.6
<i>Habrobracon</i> , 500 R.....	1	310	285	+8.0	282	294	-4.3
	2	410	397	+3.1	387	390	-.8
<i>Tribolium</i>	1	1100	1100	0	1070	1080	-.9
	2	1080	1080	0	1010	1070	-5.9
	3	812	810	+2	700	740	-5.7
	4	770	783	-1.7	710	715	-.7
<i>Drosophila</i> larvae.....	1	704	675	+4.1	625	643	-2.9
	2	684	665	+2.8	610	630	-3.3
	3	635	635	0	603	600	+5
	4	633	628	+8	590	590	0
<i>Drosophila</i> adult.....	1	1480	1490	-.7	1540	1490	+3.2
	2	1530	1520	+6	1490	1470	+1.3
	3	1530	1490	+2.6	1480	1500	-1.4
<i>Tradescantia</i>	1	315	314	+3	313	312	+3
	2	310	315	-1.6	309	308	+3
	3	207	200	+3.4	200	205	-2.5
	4	213	203	+5	205	206	-.5
	5	305	305	0	285	286	-.3
	6	288	295	-2.4	282	287	-1.8
Lysogenic bacteria, 2500 R.....	1	2200	2160	+1.8	2230	2100	+5.8
	2	2030	2070	+2.0	2070	2140	-3.4
	3	1240	1240	0	1180	1210	-2.5
	4	1270	1250	+1.5	1210	1240	-2.5
Lysogenic bacteria, 1000 R.....	5	767	740	+3.5	687	705	-2.6
	6	778	780	-.3	742	720	+3.0
	7	477	477	0	440	446	-1.4
	8	490	492	-.4	456	460	-.9
Lysogenic bacteria, 500 R.....	9	276	280	-1.4	265	265	0
	10	310	295	+1.8	300	304	-1.3
	11	215	225	-4.6	206	207	-.5
	12	230	225	+2.2	212	208	+1.9
<i>Neurospora</i> , 6000 R.....	1	3280	3200	+2.4	3500	3180	+9.1
	2	1080	1130	-4.6	1120	1100	+1.8
	3	3329	3259	+2.6	3220	3250	-.9
	4	1080	1070	+9	1130	1070	+5.3
<i>Neurospora</i> , 2500 R.....	1	1630	1600	+1.8	1670	1560	+6.6
	2	720	715	+7	664	626	+5.7
	3	1650	1600	+3.0	1560	1540	+1.3
	4	740	670	+9.5	660	665	-.8
<i>Neurospora</i> , 1000 R.....	1	680	665	+2.2	609	627	-3.0
	2	370	383	-3.5	334	328	+1.8
	3	650	665	-2.3	570	602	-5.6
	4	378	387	-2.4	342	333	+2.6
<i>Neurospora</i> , 500 R.....	1	355	370	-4.2	334	350	-4.8
	2	233	226	+3.0	220	219	+5
	3	360	360	0	337	332	+1.5
	4	220	230	-4.5	218	215	+1.4
Net percent difference.....				+0.35			-0.15

TABLE 11. — Radiation Doses to Biologics, Phase B and C Tests

Package	Exposure, R			
	Phase B		Phase C	
	301 S/C	201 S/C	301 S/C	201 S/C
<i>Tribolium</i> , 1200 R	920	920	874	903
	898	898	853	882
	865	865	822	849
<i>Drosophila</i> larvae, 1300 R	850	833	777	787
<i>Drosophila</i> adult, 2000 R	1407	1395	1398	1383
Lysogenic bacteria:				
2500 R front chambers	1685	1726	1754	1730
2500 R back chambers	1336	1368	1391	1372
1000 R front chambers	727	716	674	671
1000 R back chambers	618	608	572	570
500 R front chambers	275	270	265	273
500 R back chambers	243	238	234	241

TABLE 12. — Radiation Measurements in Control Areas, Phase B and C Tests

Package	Radiation, R			
	Phase B		Phase C	
	301 S/C	201 S/C	301 S/C	201 S/C
<i>Habrobracon</i>	0.40	0.39	0.41	0.38
	.42	.40	.46	.44
<i>Tribolium</i>	.36	.47	.39	.60
	.32	.38	.32	.35
<i>Drosophila</i> adult	.26	.26	.29	.20
	.29	.29	.30	.42
	.23	.25	.22	.18
<i>Tradescantia</i>	.28	.28	.28	.25
	.26	.27	.28	.28
	.31	.29	.28	.26
	.28	.27	.30	.28
<i>Drosophila</i> larvae	.41	.48	.50	.34
	.21	.22	.19	.18
	.34	.35	.36	.30
	.25	.31	.26	.18
<i>Neurospora</i>	.20	.19	.26	.26
	.19	.19	.18	.19
	.24	.39	.36	.35
	.22	.35	.16	.23
Lysogenic bacteria	.56	.41	.41	.41
	.41	.43	.42	.44
Ion chambers:				
1.0-R chamber	.21	.22	.19	.20
5.0-R chamber	.22	.26	.26	.30

as did the corresponding specimens in the Earth control capsule. This is indicated both by the dosimeter readings and, inferentially, by the close agreement of the strengths of the sources. The delivered doses are in agreement with an exposure time of 42 hours instead of the nominal 65 hours.

The radiation exposures in the control areas were quite low, as determined by LiF readings. Few were above 0.5 R. The ion-chamber measurements independently confirm the low values. Nuclear emulsion measurements were made of the numbers of protons and heavy ions entering the spacecraft during orbital flight. An upper limit dose due to protons is 40 mR for the mission. There were 10.1 traversals of atomic nuclei of $Z \geq 20$ through each square centimeter during the flight.

Postflight tests have been completed which have established the Earth controls based on vibration and acceleration data obtained during the flight. With respect to the radiation environment, the conditions for a successful determination of the combined effects of weightlessness and radiation have been met.

ACKNOWLEDGMENTS

A. F. Braun and E. Kelly, PAA, Patrick Air Force Base, provided invaluable health physics support during the launch. Special thanks are also due L. Juhos, M. Gocal, and C. Hartman of Stanford Research Institute for the LiF readout.

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